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Effects of Alkaline Hydrogen Peroxide-treated Fiber Ingredients on Mixograph Properties of Wheat Flour Dough

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The mixograph performance of doughs containing high-fiber cereal-plant fractions such as corn or wheat bran, oat or soybean hulls, sugar beet pulp, corn cob chaff, ground corn cobs, and distiller's spent grains was improved when the plant fractions were pretreated with alkaline hydrogen peroxide (AHP). Doughs in which AHP-treated corn bran replaced 10% of flour exhibited 40–50% higher mixograph peaks than straight-flour doughs over a wide absorption range. Other AHP-treated materials tested also increased the mixograph peak height, but to a lesser extent. Untreated materials and highly purified celluloses decreased the mixograph peak height. At high moisture levels, AHP-corn bran also greatly reduced the mixing time required to reach the mixograph peak.

Introduction

Incorporation of high-fiber ingredients such as cereal brans, seed hulls and purified cellulose into baked foods is limited to relatively low levels because these materials can reduce baked volume and introduce undesirable gritty textures. These effects can be traced, at least in part, to the tendency of both natural plant cell walls and purified cellulose fractions to hydrate primarily on their surface (1). These rigid, incompletely hydrated particles function as inclusions, weakening dough by cutting gluten strands (2).

Recently, we reported that treatment of natural plant cell walls with a dilute, alkaline solution of hydrogen peroxide removes a portion of the lignin present in the cell walls, leaving a partially delignified product with greatly increased water absorbency and improved softening and swelling characteristics (1,3). Using wheat straw (WS) and corn stalks (CS) as model lignocellulosic substrates, we found that alkaline hydrogen peroxide (AHP)-treated WS and CS could be incorporated into dough and batter formulations in place of flour at high levels without reducing baked volume and sensory characteristics of breads and cakes (4,5).

Wheat straw and corn stalks were selected as model substrates for our earlier studies because the effects of AHP-treatment on the chemical composition and morphological properties of these materials had already been well characterized (6,7). Interest in the possibility of applying AHP-treatment to more conventional, food-grade substrates has now led us to conduct a preliminary evaluation of the effects of AHP-treatment on a variety of lignocellulosic materials, including corn bran, that are potentially suitable for human consumption.

*The mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

Material and Methods

Lignocellulosic substrates (corn bran, oat hulls, wheat bran, soybean hulls, corn cob chaff, ground corn cobs, sugar beet pulp and distiller's spent grains) were treated with a dilute, alkaline solution of hydrogen peroxide (pH 11.5) as described in detail elsewhere (8,9). Briefly, the treatment consisted of suspending 10 g (dry weight) of the lignocellulosic substrate in 500 ml of distilled water containing 1% (w/v) hydrogen peroxide. The suspension was adjusted to pH 11.5 with NaOH and stirred gently at room temperature for 14–17 h. The suspension was then adjusted to pH 6 with HCl, and the insoluble portion collected by filtration. The treated materials were washed with water and dried in a forced-air oven (Proctor Schwartz) at 40°C for 24 h. Dried, treated samples were ground in a Wiley mill to pass a 0.5 or 1.0 mm screen. Commercially available, highly purified cellulose additives were obtained from James River Corp. (ground wood pulp, 'Solka Floc' SW-40), ICN Biochemicals (alpha-cellulose), and FMC Corp. (microcrystalline cellulose, 'Avicel'). Samples of corn brans (wet-milled and dry-milled), wheat bran, oat hulls, soybean hulls, corn cob chaff, ground corn cobs, sugar beet pulp, and distiller's dried grains were also obtained from commercial sources.

The effects of replacing 10% by weight of flour with various cellulosic fibrous materials on the rheological properties of flour-based doughs were measured in a mixograph using the method of Finney and Shogren (10). Dry samples of wheat flour ('Pillsbury's Best' bread flour, 12.4% protein) and cellulosic fibrous material were carefully weighed and mixed as necessary before being placed in the mixograph bowl (total sample dry weight = 10 g). A hole was created in the center of the flour-based mixture in the mixograph bowl, and a carefully measured quantity of water was added. The mixograph was then operated for 15–25 min, and the degree of deflection of the mixograph arm was recorded on a strip chart recorder. The point of maximum deflection (peak) corresponds to the point of optimal dough properties (11,12). Time to peak (min) and peak height (cm) were determined from the strip chart recordings of the mixograph response. All experiments were performed in duplicate with a 10 g National Mfg. Co. mixograph (Lincoln, NE).

Results and Discussion

Alkaline hydrogen peroxide treatment was found to be effective on a wide range of food-grade lignocellulosic materials (**Table 1**). The greatest increases in mixograph peak height were seen in doughs containing AHP-treated corn brans. Doughs containing the following AHP-treated materials showed the smallest changes in mixograph peak height compared to flour alone: wheat bran, oat hulls, soybean hulls, corn cobs and distiller's spent grains. Nevertheless, all of the doughs containing AHP-treated substrates exhibited higher mixograph peaks than doughs containing the same levels of the corresponding untreated substrate or purified cellulose.

It is well known that the height of the mixograph peak for doughs made with flour alone decreases linearly as the water content of the dough is increased (**Fig. 1**). As expected, replacement of 10% of the flour (dry weight basis) with untreated corn bran or alpha-cellulose caused a decrease in the height of the mixograph peak at all dough moisture levels tested. Similar or greater decreases in mixograph peak height were also observed when microcrystalline cellulose, Solka Floc, or untreated oat hulls were substituted for 10% of flour (not shown). In contrast, replacement of 10% of the flour with alkaline peroxide-treated corn bran (AHP-CB) caused a large increase in the height of the mixograph peak over the range of moisture levels tested, and allowed the formation of acceptable doughs at moisture levels too high for the formation of doughs made from flour alone.

The increase in mixograph peak height caused by AHP-treated substrates represents unusual behavior for a cellulosic material in a flour dough. Assuming that the height of the mixograph peak primarily represents an increase in tensile strength of the dough, substitution of non-functional cellulosic material for a portion of the flour in a dough should reduce peak height because: (i) the gluten content in the dough mixture is reduced, and (ii) the cellulosic component acts as a diluent, interfering with the formation of the optimum starch/gluten matrix. When stretched during mixing and raising, gluten strands would tend to break at the interface between the rigid, poorly hydrated cellulose particle and the starch/gluten matrix. Improving the ability of the cellulosic additive to hydrate more extensively and soften might be expected to increase the height of the mixograph peak by reducing or eliminating the latter effect.

The amount of water available in a dough to hydrate starch and gluten exerts a strong effect upon both its mixograph peak height and the mixing time required to reach the peak. However, it is probably overly simplistic to assume that the effects of AHP-treated lignocellulose on mixograph performance are attributable solely to its ability to absorb and sequester water. For example, more purified cellulose fractions, such as Solka Floc and microcrystalline cellulose, exhibit water absorbencies similar to some AHP-treated lignocellulosics, but do not increase the mixograph peak height for doughs into which they have been incorporated (1,3,4). Purified cellulose fractions tend to bind water mainly on particle surfaces, retaining a dry, rigid interior. In contrast, particles of AHP-treated lignocellulosics tend to hydrate more uniformly, achieving a softer, more pliant form. The resulting deformability may allow the individual particles to respond better to the mechanical forces experienced by the dough during mixing and development, providing a stronger interface between the lignocellulosic particle and the starch/gluten matrix.

The time required for all-flour doughs to reach a peak in the mixograph increased dramatically at absorption levels >61%. Interestingly, this increase in mixing time was greatly reduced when a portion of the flour was replaced with AHP-CB (**Fig. 2**), suggesting that the AHP-CB could also be used as an additive to reduce time and/or energy requirements for mixing high-moisture doughs such as those used in reduced calorie breads. Unlike most of the AHP-treated lignocellulosics and commercially available fiber additives we have tested (4), AHP-corn bran did not increase dough mixing time, with mixograph peaks occurring at about 5–6 min over a dough absorption range of 61–91%. Again, it seems unlikely that water absorption alone could be responsible for this effect,

Table 1 Effect of various lignocellulosic materials on mixograph peak height of wheat flour dough

Fiber added*	Screen size (mm)†	Mixograph peak height (cm) Absorption	
		61%	71%
None	—	5.6	4.9
Corn bran	0.5	5.1	4.4
Corn bran	1.0	5.2	4.3
AHP-corn bran	0.5	7.8	6.8
AHP-corn bran	1.0	7.4	6.7
AHP-corn bran	0.5	7.1	6.1
AHP-corn bran	0.5	6.6	5.9
AHP-corn bran	0.5	6.3	6.0
AHP-corn bran	0.5	6.4	5.8
AHP-corn bran	1.0	6.0	5.6
Oat hulls	1.0	4.9	4.3
AHP-oat hulls	1.0	5.7	5.0
AHP-wheat bran	0.5	5.7	5.1
AHP-wheat bran	1.0	5.7	5.0
AHP-soybean hulls	1.0	5.4	4.9
AHP-cob chaff	0.5	6.0	5.2
AHP-ground cobs	0.5	5.9	5.0
Sugar beet pulp	1.0	5.8	5.1
AHP-sugar beet pulp	1.0	6.4	5.5
AHP-distiller's spent grains	1.0	5.7	5.2

*10% replacement of flour.
†Samples were ground in a Wiley Mill to pass the indicated screen

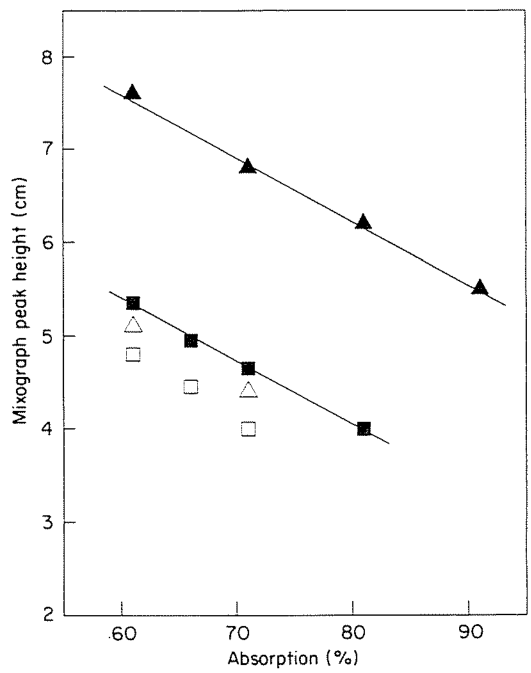

Fig. 1 Effects of various cellulosic and lignocellulosic materials on mixograph peak height of a wheat flour dough at different absorptions. The materials were substituted for 10% (1 g) of the flour in a 10 g mixograph assay as described in Methods: (■) flour (no substitution): (▲) alkaline hydrogen peroxide-treated corn bran (AHP-CB) (wet-milled), 0.5 mm; (△) untreated corn bran (wet-milled), (finely ground); (□) alphacellulose

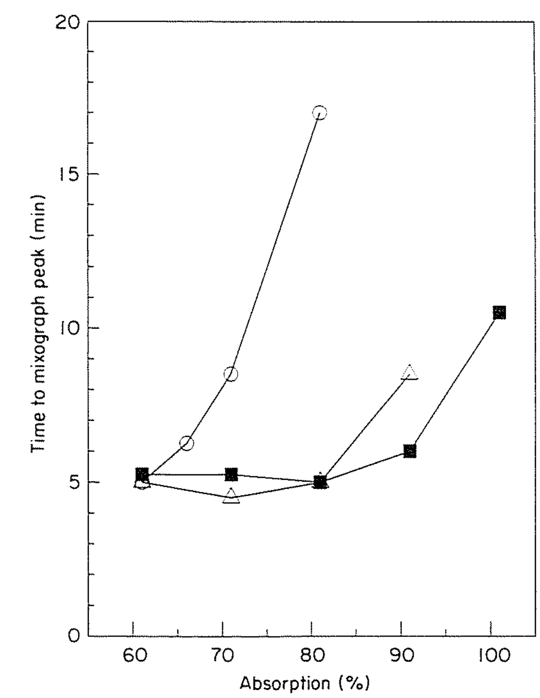

Fig. 2 Effect of dough absorption on the time required to reach the mixograph peak for wheat flour doughs containing AHP-CB. Open circles (○) indicate the mixing times required for 10 g of wheat flour at various absorption levels. The mixing times required for a mixture containing 9 g flour plus 1 g AHP-CB (wet-milled) are indicated by the solid squares (■, 0.5 mm grind) and the triangles (△, 1 mm grind)

because other AHP products with similar or better water absorbencies exhibited increased mixing times (4).

At present the reasons for the differences in the responses of various lignocellulosic substrates to AHP-treatment are unknown. It is likely that the chemical composition of the cell walls, including type and amount of lignin and hemicellulose, influences the extent of the AHP-dependent reactions and thus the physical properties of the treated product (8). It is therefore reasonable to expect that particular AHP-treated substrates may be better suited for use in some products than in others, depending upon the properties desired.

The data presented here and elsewhere (1,3–5) demonstrate that AHP-treatment is a useful method for improving the properties of natural lignocellulosic substrates for use in foods. The AHP process is effective on a wide range of food-grade substrates, including cereal brans, seed hulls, and fruit and beet pulps, and is particularly effective on corn brans. Mixograph data for wheat flour doughs have been shown to be an excellent predictor of final loaf volume, but there are many other considerations (11,12). For example, the loaf must be able to sustain itself during proofing, without excessive outgassing. The effect of fiber particle size on gas loss during proofing and baking must therefore also be determined. The purpose of this communication is to illustrate that AHP-treated lignocellulosics, especially AHP-corn bran, exhibit some desirable properties in doughs, as measured by the mixograph. Incorporation of AHP-treated corn bran in place of a portion of the flour increases dough strength, allows the use of higher water contents, and reduces the mixing time required to reach optimal dough strength. These properties are consistent with emerging commercial applications of AHP-treated lignocellulose as a high-fiber, non-caloric flour substitute.

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